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Research Article

Performance improvement of shell and tube heat exchanger by using Fe_3O_4/water nanofluid

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ABSTRACT

The objective of this paper is to study the effect of nanofluid on the performance of the heat exchanger, as well as the heat transfer rate, coefficient of total heat transfer, friction influence and average Nusselt number, and thermal efficiency factor and has been investigated and discussed. In this work, the output heat transfer of Fe3O4/water nanofluid through shell and tube heat exchanger has been numerically investigated under laminar flow. CFD simulations with ANSYS FLUENT 2020R1 were used adopting finite volume approach to solve the governing equations. Numerical calculations were carried out for Reynolds numbers ranging from 200 to 1400, with nanoparticles as the volume fraction (0.2% and 0.35%). The results show that the augmentation in increase Nusselt number and amount of heat transfer rate and the efficiency of nanofluid at the concentration of 0.35% are approximately 19%, 25% and 12% respectively. It was observed through the results that the friction decreases as the Reynolds number increase.

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INTRODUCTION

The usage of nanofluids to upsurge convective heat transfer performance has been a focus of researchers in recent years. Heat exchangers are used to transfer heat among dissimilar-temperature fluids while preventing them from mixing. Thermo fluid systems can be used for a variety of purposes, including: heat exchangers (heat pipe H.E, shell tube H.E, dual pipe H.E, etc) and a ventilation system for automobiles (radiator in a vehicle).

Heat exchangers made of shell and tube are effective, inexpensive, and capable of transferring large amounts of heat. In comparison to other kinds of exchangers, such as flat plate and pressurized heat exchangers, Heat exchangers of shell and tube come in a variety of sizes and designs, this type of exchanger can accommodate a wide range of flow rates while reducing pressure drop. Nanofluids are classified as metallic and non-metallic particles ranging from 1 to 100 nanometers in diameter that disperse in a liquid for example glycerol, ethylene glycol, water, or oil [1]. In the last few years, several authors have looked into the properties of nanocomposites, and it is anticipated that the next

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generation of heat transfer technology will be the best due to its superior thermal efficiency over conventional heat transfer fluids [2]. Nanoscale materials have different thermophysical and mechanical properties from simple materials, which is one of the reasons for their widespread usage [3].

There are two types of heat exchangers:

1. Direct contact heat exchangers are those in which both medium in which heat is transferred are in direct touch with each other.
2. An indirect contact heat exchanger is one in which the two mediums are separated by a wall through which heat is transmitted so that they never combine.

The shell and tube heat exchanger is a common heat exchanger for greater pressure applications up to 552 bars.

Heat exchangers with shell and tube construction, as well as heat exchangers with indirect contact. It's made up of a series of tubes that one of the fluids passes through. The shell fluid is contained in the shell. Although shells of various shapes are employed in specialized applications, it is generally cylindrical in shape with a circular cross section.

Numerous numerical studies have been conducted on improving the performance of the shell-and-tube heat exchanger by using nanofluids. One of these studies was done by the researcher Somasekhar et al. [4] conducted a numerical study using the simulation program to improve the heat transfer in the shell and tube exchanger by using Al_2O_3/water nanofluid as a cooling medium instead of distilled water and by volume ratios (0.3%,0.5%,0.75%,1%.2%). Where this research study was conducted to study the effect of pecklet number and the type of particles and volumetric ratios on heat transfer. The results showed that adding nanoparticles to distilled water leads to an improvement in the heat transfer properties. The results also showed that the Nusselt number increases as the concentration of nanoparticles increases and Pecklet number. The results also showed that the pressure drop increases more than when using distilled water. Saberi et al. [5] used single-phase and batter models to compare the effects of three nanofluids exposed to forced thermal transfer in a horizontal tube under constant wall temperature circumstances. According to the findings, the two-stage mixture model matched better, and as particle concentration rises, so does the heat transmission coefficient, and heat transmission is increased by increasing the number of Peclets. Kalteh et al.[6] in a laminar flow device, a computational study of forced convection is used to transfer heat of copper- aqueous nanofluid inside a thermally heated nanotube was performed. By using a bimodal Eulerian fluid, the heat transmission property of the nanofluid was simulated. According to the results, as the Reynolds number and particle concentration increase the heat transfer efficiency increases. Heat transmission on the other hand upsurges as the diameter of the nanoparticle's reduction and the decrease in pressure of nanofluids was also marginally greater than that of basic liquids. Raja et al. [7] the researcher conducted a theoretical study on the laminar flow system, through the thermal transfer of nanofluid flow via a straight round when the boundary conditions are constant of the heat flow. The findings showed that the concentration of nanoparticles and Brownian motion are significant sources for improving heat transmission performance, while the diameter of the nanoparticles has an adverse effect on the thermal transfer efficiency. Raju and Srinivasulu [8] they studied thermal analysis in a shell and tube heat exchanger by using Titanium Carbide, Titanium Nitride, and Zink Oxide Nanofluids. When compared to other fluids in CFD simulation, Titanium Nitride nano fluid with copper tubes produces a greater heat flux. B. H. Chun et al [9] experimental approaches were used to analyze the convective transport coefficient for nanoparticles of aluminum oxide and transformer oil flowing through a dual pipe heat exchanger in a laminar flow state. The results revealed that as the concentration of nanofluid upsurges, the convection coefficient upsurges. Furthermore, Nanoparticle surface properties, particle loading, and particle shape all play a role in improving nanofluid heat transport properties. Milad and Ehsan [10] investigated the impact of various factors on the thermal efficiency of graphene oxide nanofluids in a shell and tube heat exchanger using exergy analysis. The findings revealed that graphene oxide nanofluids improve heat transmission in both laminar and turbulent flow regimes. Akhtari et al. [11] were investigation the heat transfer properties of Al_2O_3/water nanofluids in a shell and tube, as well as in a twin pipe heat exchanger by using experimental and CFD analysis. At a volume concentration of 0.5 %, they discovered a substantial increase in heat transfer coefficient of up to 23.9%. Dhaiban et al [12] conducted numerical simulations using Al_2O_3/water nanofluid to improve the heat exchange of the shell and tube heat exchanger at 1%, 2%, 3%, 4% as volume ratios. The results showed that there is a good agreement between the numerical data for water and the results obtained from the Gnielinski correlation with a maximum deviation of about 3%. The simulation also showed that at Re = 7500 and 4% concentration, there was an increase in Nusselt number and convective heat transfer coefficient by 9.5% and 13.5%, respectively.

Based on what was discussed in previous studies and research on improving the performance of the shell-and-tube heat exchanger by using various nanofluids, but little has been done by researchers in the field of using Fe_3O_4/water nanofluid in improving the heat transfer properties. In this study, the effectiveness of this material and how to improve the performance of the shell and tube heat exchanger will be demonstrated. In the present work, consideration was given to the effect of nanofluids on the rate of heat transfer, the coefficient of friction and the Nusselt number in the condition of laminar flow, the Reynolds number and nanoparticle concentration ranged from 200 to 1400, 0.2% and 0.35%, respectively. Constant entry temperature, entry velocity, and exit pressure are part of the simulation's boundary conditions. For the heat exchanger applications in this analysis, potential convection stimulated heat transfer while increasing the thermal properties and thermal energy efficiency of the nanofluid.

THE NANOFLUID'S PHYSICAL PROPERTIES

For the physical properties of distilled water and Fe_3O_4 nanofluid (viscosity (*μnf*), density (ρ_{nf}), thermal conductivity (K_{nf}), specific heat (Cp_{nf})) are shown in Table (1). To extract the theoretical values for the properties of the nanofluids, the equations below are used [13].

$$\mu_{nf} = \mu_{bf}(1 + 2.5\emptyset) \tag{1}$$

$$\rho_{nf} = (1 - \emptyset)\,\rho_f + \emptyset\rho_p \tag{2}$$

$$k_{nf} = \frac{k_p + 2k_w + 2(k_p - k_w)\emptyset}{k_p + 2k_w - (k_p - k_w)\,\emptyset}\,k_w \tag{3}$$

$$Cp_{nf} = \frac{(1-\emptyset)(\rho c_p)_f + \emptyset\,(\rho c_p)_p}{(1-\emptyset)\,\rho_f + \emptyset \times \rho_p} \tag{4}$$

Based on the density of the base fluid (ρ_f) and nanomaterial density (ρ_p) at 293.15 K°, equation (5) was used to calculate the concentration of the nanofluid [14].

$$\varphi_v = \frac{\dfrac{W_{Fe_s}o_4}{{}_{Fe_s}o_4}}{\left[\left(\dfrac{W_{Fe_3}o_4}{\rho_{Fe_s}o_4}\right) + \left(\dfrac{W\square\square\square\square\square\square}{\rho\square\square\square\square\square\square\square}\right)\right]} 100\% \tag{5}$$

In this study, Fe_3O_4 nanoparticles of (20-30) nm is used and mixed at a concentration of (0.2%, 0.35%) with pure water as a basic liquid. The table (1) demonstrates the characteristics of pure water and nanoparticles.

Where: (ρ) density, (μ) viscosity, (Cp) specific heat, (K) thermal conductivity.

NUMERICAL ANALYSIS

Computational fluid dynamics (CFD) is a technique for predicting fluid movement, heat and mass transfer, chemical reactions, and a variety of other engineering problems involving fluid flow, the specific problem is expressed in the form of a mathematical model that controls the physical equation. This is accomplished through the use of numerical techniques. In this paper, we seek to improve the heat exchanger of shell and tube performance by reaching the optimum design by means of computer modeling [16]. Computational fluid dynamics (CFD) technology, which contains different numerical methods and a number of computer algorithms, has been used to solve and analyze problems that include fluid flow.

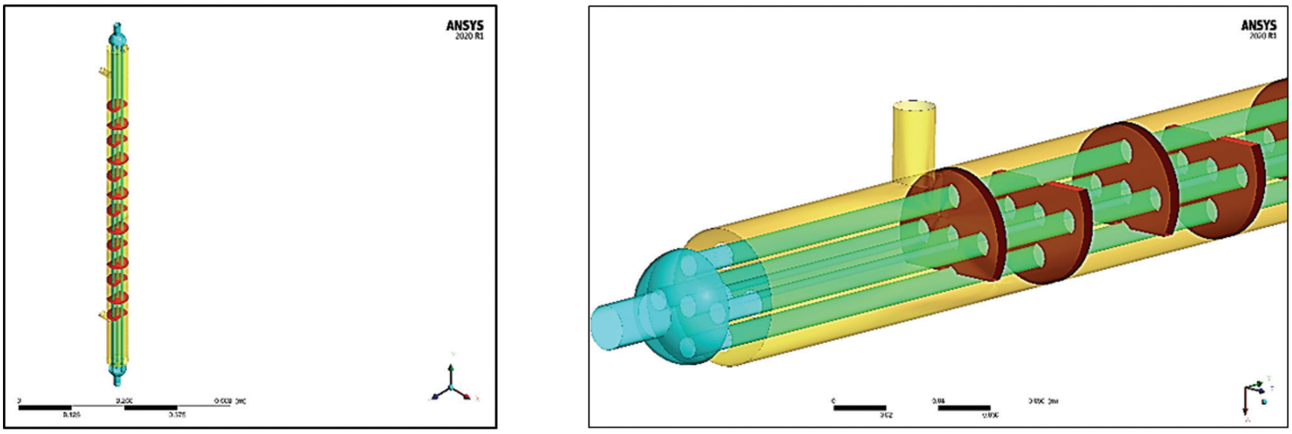
This technique allows the researcher to know the enthalpy distribution, the entropy distribution, kinetic energy, turbulence intensity, density and other parameters, but in our study, we will be satisfied with the distribution of pressure, temperature and velocity. Calculations required to simulate fluid flow with surfaces defined by boundary conditions, and the initial conditions are done by ANSYS FLUENT 2020R1. The Navier stokes equations form the primary basis for solving fluid dynamics problems. The Continuity equation, Energy equation and the Navier-Stokes equation govern the fluid flow within the exchanger.

Numerical Procedure

The numerical procedures of the program are divided into four main parts, namely: First, drawing the geometric shape of the laboratory space that is shown in Figure (1) with real dimensions and determining the direction of flow. Secondly, the distribution of the network of points on all parts of the space that is decreed, as the optimal distribution of points must be chosen, and at this stage the optimal network is tested (Grid Independent Test). Third, control and choose the governing equations, as the program contains equations covering most types of heat transfer and flow, determining the type of fluid used and the mineral, establishing the studied space's boundary conditions (wall, velocity inlet, axis, pressure outlet) and choosing the solution method. Fourth, the final step is to check the results of the solution, either with practical values or with theoretical equations, and if the results of the solution are not close to the results to be compared with, then the independence test of the network is applied, which is to increase the size of the divisions in the arithmetic field and then repeat the loop again until it is reached close values of the results to be compared with, after which the solution ends, and the final results are extracted. In the simulation of the search model, the model was divided into seven values represented by the number of elements according to the following (1534267,

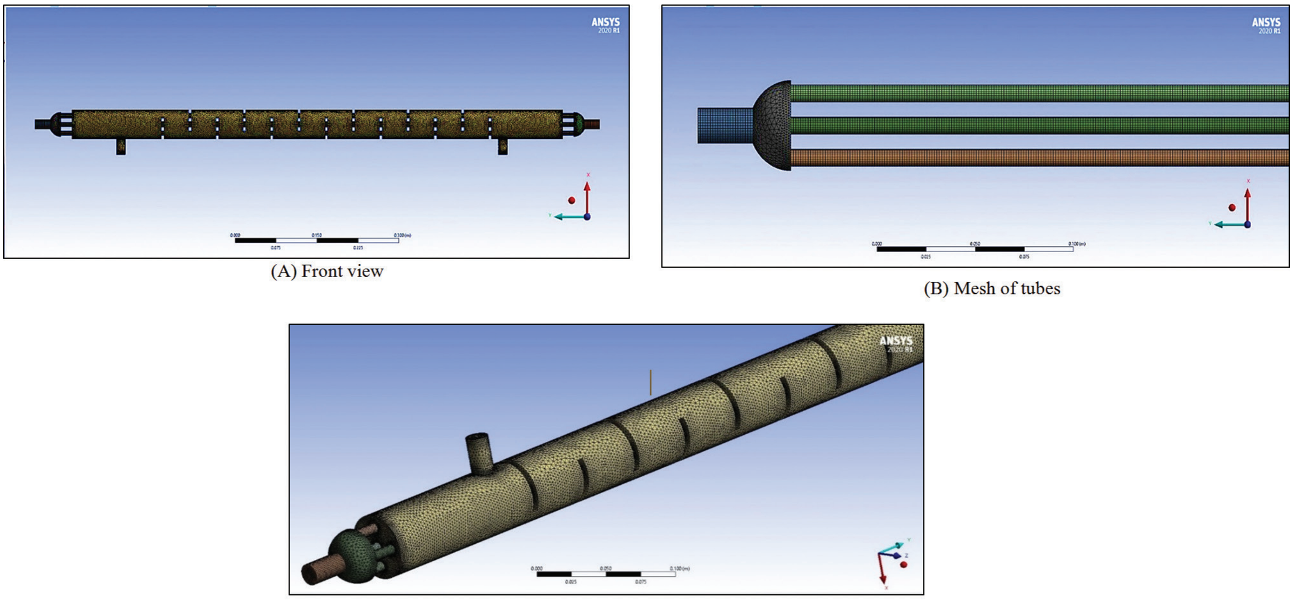
Table 1. Characteristics of water and nanomaterial at temperature of 293.15 K°

Medium	Cp, (J/kg.k)	μ, (Pa.s)	K, (W/m.k)	ρ, (kg/m³)	T (K)
Water	4182	0.001	0.6	998.2	293.15
Fe_3O_4 [15]	670	-	80.4	5180	293.15



(a) Isometric view (b) Side view

Figure 1. Heat exchanger geometry.



(A) Front view

(B) Mesh of tubes

(C) Mesh of shell

Figure 2. Mesh of heat exchanger.

1976544, 2650487, 3466769, 4450388, 5788429, 6350788) and dependent on the Reynolds number with the lowest value (Re = 200) and the Figure (2) shows the grid of the heat exchanger test bench at the tetrahedral element. Then the test was performed and obtained (6350788) element, where a constant temperature and Nusselt Number were obtained with this value and thus the work was started and relied on the last value obtained as shown in the Figure (3).

Data Collection

In the current research, Fe_3O_4 nanoparticles dispersed in pure water were used to examine the efficiency of nanofluids, as well as the coefficient of thermal Convection and Nusselt number. Consequently, the following equations can be used to calculate it.:

The base fluid's and nanofluid's heat transport rates can be computed using the formula below:

$$Q = \dot{m} \cdot C_p \Delta T \tag{6}$$

The Nusselt number and coefficient of thermal convection of the base fluid and nanofluid can be determined using the formulas below:

$$Nu = \frac{hD}{k} \tag{7}$$

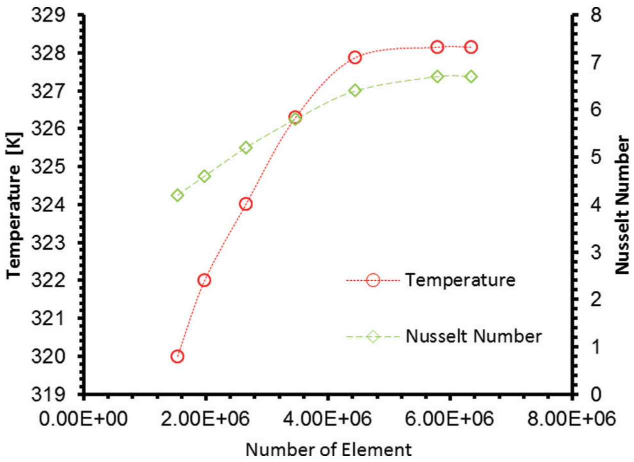


Figure 3. Grid Independent Test.

$$h = \frac{Q}{A(T_w - T_{,b})} \quad (8)$$

Where:

$$T_f = \frac{T_{in} + T_{out}}{2} \quad (9)$$

To compute the nanofluids' total heat transmission coefficient within the tube through the following formulas [14].

$$\frac{1}{U_i} = \frac{1}{h_i} + \frac{D_i \mathrm{Ln}\frac{D_o}{D_i}}{2k_w} + \frac{D_i}{D_o} + \frac{1}{h_o} \quad (10)$$

According to the nanofluid and base fluid used, the percentage of efficiency is calculated from below equation for laminar flow [18].

$$\eta = \left(\frac{Nu_{nf}}{Nu_f}\right) / \left(\frac{f_{nf}}{f_f}\right)^{\frac{1}{3}} \quad (11)$$

To calculate the Nusselt Number theoretically using different correlation, shah London [19], Sieder-Tate [20], new correlation developed[21], respectively and compared with CFD result

$$\mathrm{Nu} = 4.364 + 0.0722\left(\mathrm{Re}_{D_h}\ \mathrm{Pr}\frac{D_h}{L}\right) \quad \text{for } \left(\mathrm{Re\,Pr}\,D_h/L\right) < 33.33 \quad (12)$$

$$\mathrm{Nu} = 1.953\left(\mathrm{Re}_{D_h}\ \mathrm{Pr}\frac{D_h}{L}\right)^{\frac{1}{3}} \quad \text{for } \left(\mathrm{Re\,Pr}\,D/L\right) >= 33.33 \quad (13)$$

$$Nu = 0.4381 Re^{036} Pr^{042} \quad (14)$$

Table 2. Geometric dimensions of the heat exchanger

Dimension	Measurement
Length of shell	980 mm
Length of tube	900 mm
Number of tubes	5
Number of baffles	13
Inlet diameter (inner tube)	8 mm
Outlet diameter (inner tube)	10 mm
Inlet shell diameter	50 mm
Outlet shell diameter	60.5 mm
Picth tube	21 mm
Surface area	0.11
Buffle cut	25 %

$$Nu = 3.66 + \frac{0.065\, RePr\frac{D}{L}}{1 + 0.04\left(RePT\frac{D}{L}\right)^{2/3}} \quad (15)$$

RESULTS AND DISCUSSION

The heat transmission augmentation when used nanofluids was investigated in a counter flow of shell and tube heat exchanger using nano-powder Fe_3O_4 with a base fluid of deionized water with two volume fractions of (0.2% and 0.35%) and four Reynolds numbers of (200, 600, 1000, 1400).

Validation of Current Data

To validate the results of the current study, corrected equations from Nusselt number are used to find out the extent of the match between the extracted results and the corrected equations. The numerical results were compared with the theoretical equations (Shah-London and Sieder-Tate and correlation of equation (18)), it was found through Figure (4) that there is a good convergence between the current study and with the used equations.

Figure (5) depicts a standard example of water and nanofluid temperature distribution with (Re =200) 0.2% vol, 0.35% vol, respectively. The temperature distribution through the heat exchanger is depicted on the color diagram. We notice through the color chart that the temperature from the bottom is the lowest, and then it starts to rise during the rise of the liquid to the top of the exchanger, while it meets the hot liquid from the top, and the heat exchange occurs between the two parties and by observing the shape, we see the hot liquid while going down to the bottom, losing large quantities of Its temperature and thus the cold liquid acquires it.

Figure (6) show the streamline of velocity along the heat exchanger. It was indicated the velocity flow line along the heat exchanger. We notice from the figure that the velocity is gradually distributed from entry to and during entry into the pipes.

Nusselt number

Figure (7) shows the variation in Nusselt number with different Reynolds number for tube side in the case of counter flow and with different volume fractions of nanofluid (Fe_3O_4/water), (0.2%, 0.35%). Based on the results obtained, we notice from the figure that the Nusselt number increases as the particle concentration increases and the Reynolds number increases. The maximum enhancement of the nanofluid Nusselt number was determined at 0.2% and 0.35% about 10%, 19%, respectively. The reason for this increase is due to the different thermal properties of the nanofluid from the distilled water. The findings of this

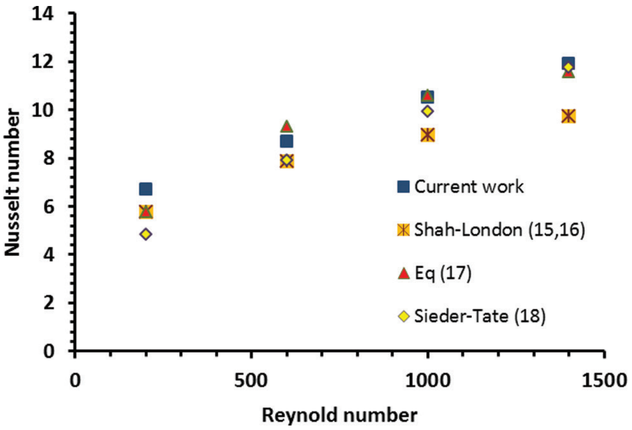


Figure 4. Validation with base fluid.

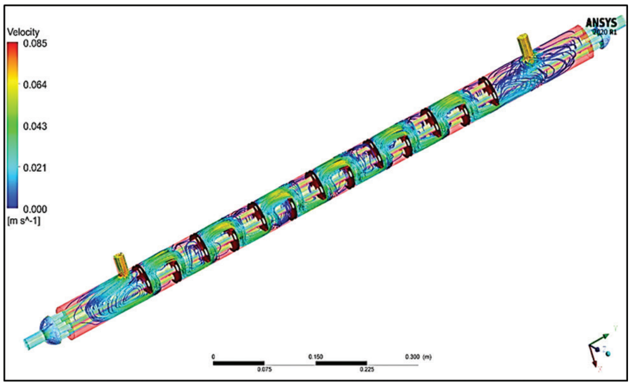
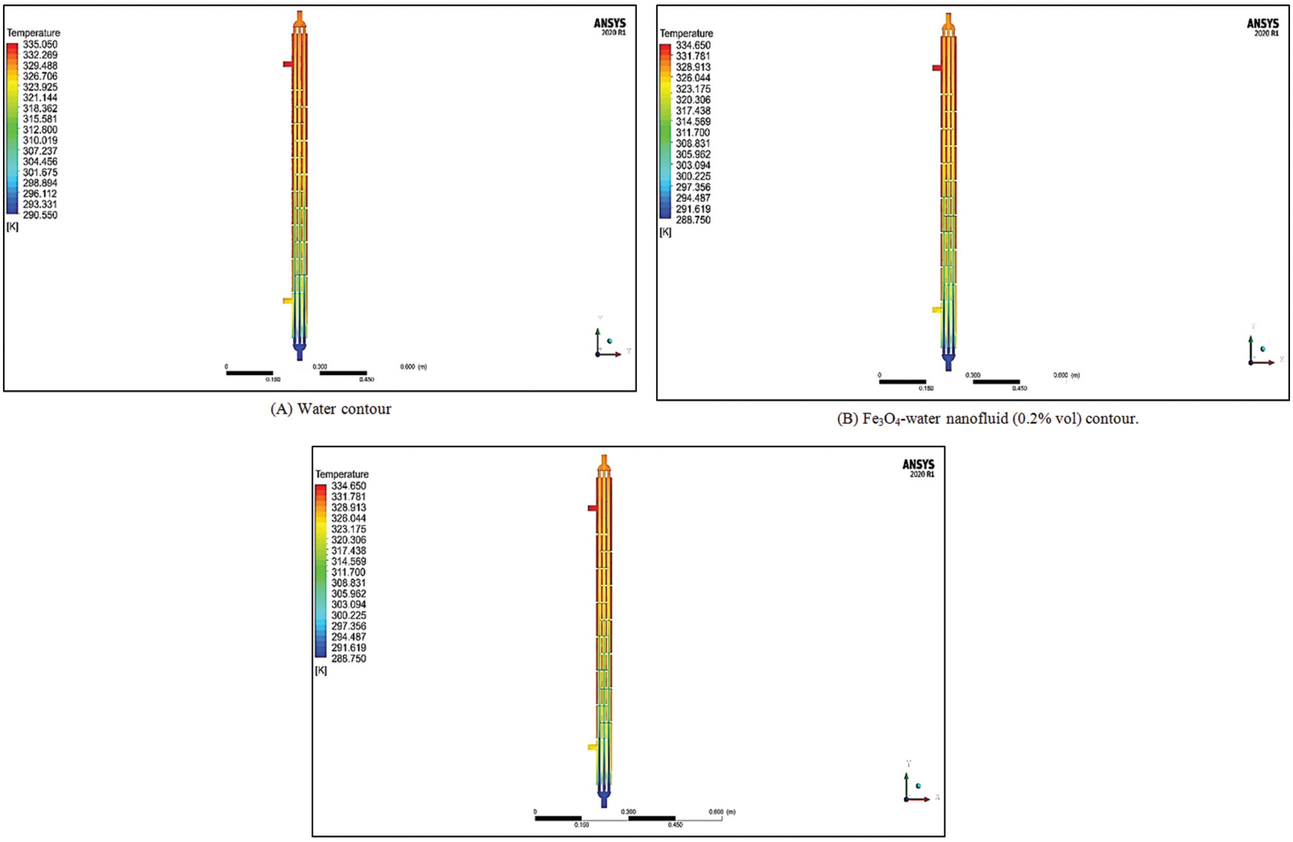


Figure 6. Stream line of velocity.



(A) Water contour

(B) Fe_3O_4-water nanofluid (0.2% vol) contour.

(C) Fe_3O_4-water nanofluid (0.35% vol) contour.

Figure 5. Contours of temperatures distribution.

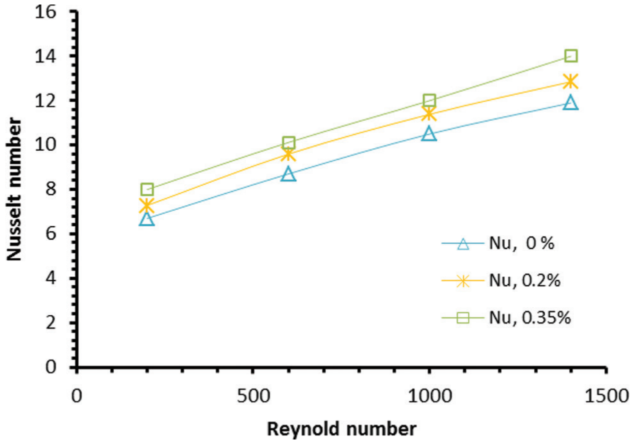


Figure 7. Various Reynolds numbers with Nusselt number.

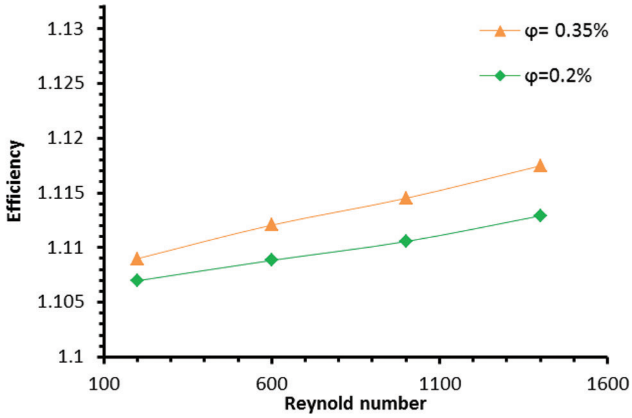


Figure 8. Thermal performance factor at various Reynolds numbers.

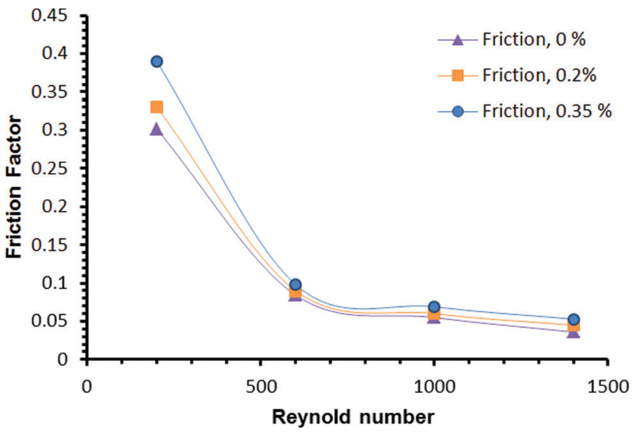


Figure 9. Friction factor at different Reynolds numbers.

research are similar in terms of the principle of the increase in Nusselt Number with the researchers **Ramirez-Tijerina et al [21] , Barzegarian [18], and Hazbehian [22].**

Performance Evaluation Coefficient

Figure (8) shows the performance factor of the nanofluid for different Reynolds number. According to the obtained results, we note that the coefficient of thermal performance is always greater than one. It is clear that nanofluids perform better than water by greatly improving heat transfer performance although higher viscosity increases pressure drop. Therefore, we note that the performance coefficient increases with the increase of the nanofluid concentration and flow rate. This increase may be due to a higher flow rate, which leads to severe turbulence and thus more particle collisions and thus leads to an increase in heat transfer. It can be inferred from this result that higher concentrations of nanoparticles in the base fluid cannot guarantee better overall performance because higher concentration causes higher viscosity which leads to lower pressure and reduced momentum. As a result, in terms of friction factor and heat transfer, the use of Fe_3O_4/water in concentrations of 0.2% and 0.35% is critical. The enhancement of heat transfer increases with higher concentration of nanofluids as shown in the figure. According to what the researcher Darzi [23] stated that as the concentration of nanofluids and Reynolds number upsurge, the overall thermal efficiency increment. And that the results of the current study took the same behavior in the increase in the improvement factor with the researcher **Hazbehian [22].**

Friction Factor

Figure (9) shows the variation in the friction factor with different Reynolds number at the volume fractions (0.2%, 0.35%) for the nanofluid. As shown in the figure, the coefficient of friction decreases with increasing Reynolds number, while it increases with increasing concentration of nanoparticles in the base fluid, and this is consistent with most researchers. Where this decrease in the coefficient of friction is attributed to the increase in the density and viscosity of the nanofluid when adding nanoparticles to the base fluid (pure water). The increase in the friction coefficient at the volumetric ratios was 0.2%, 0.35% is 25% and 47% respectively. The study's friction factor results agree with **Hussein [20] and Barzegarian [18].**

CONCLUSION

Convective heat transfer and flow properties through nanofluid in STHE have been investigated numerically. Fe_3O_4 nanoparticles of about 30nm diameter used below conditions of laminar flow in counterflow heat exchanger of shell and tube. The following conclusions were made based on the findings.

1. When a nanofluid is used, a higher Nusselt number and total heat transmission coefficient was observed,

with the reinforcement of the Reynolds number. It was also found that a certain number of Reynolds an increase in the two factors above when using nanofluid at a higher concentration.

2. Adding Fe_3O_4 nanoparticles to the base liquid augmented its thermal conductivity. The heat transmission can be influenced by friction between fluid and nanoparticles, Brownian nanoparticulate movement, and decreasing border layer thickness.
3. As for the coefficient of friction, it was observed that there is a slight increase when using the nanofluid.
4. It was noticed through the results that a high improvement was obtained in the performance of heat transfer when using the nanofluid, and the maximum improvement factor was at a concentration of 0.35%, reaching approximately 12%.

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

NOMENCLATURE

Nu	Nusselt number
Cp	Specific heat, J/kg.k
K	Thermal conductivity, W/m.k
h	Convective heat transfer coefficient, W/m^2. k
Q	Rate of heat transfer, W
T	Temperature, K
D	Diameter, m
L	Length, m
A	Area of heat transfer, m^2
U	Overall heat transfer coefficient, W/m^2. k
η	Performance factor
T_f	Fluid temperature, k
Re	Reynold number
Pr	Prandtl number
T_{in}	Inlet temperature, k
T_{out}	outlet temperature, k
D_h	Hydraulic diameter, m
$\dot{m}$	mass flowrate, kg/sec
$\vec{V}$	Velocity, m/sec
ρ	Density, kg/m^3
CFD	computational fluid dynamic
T_w	Wall temperature, k

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